# Technology transfer to industry and novel processing techniques


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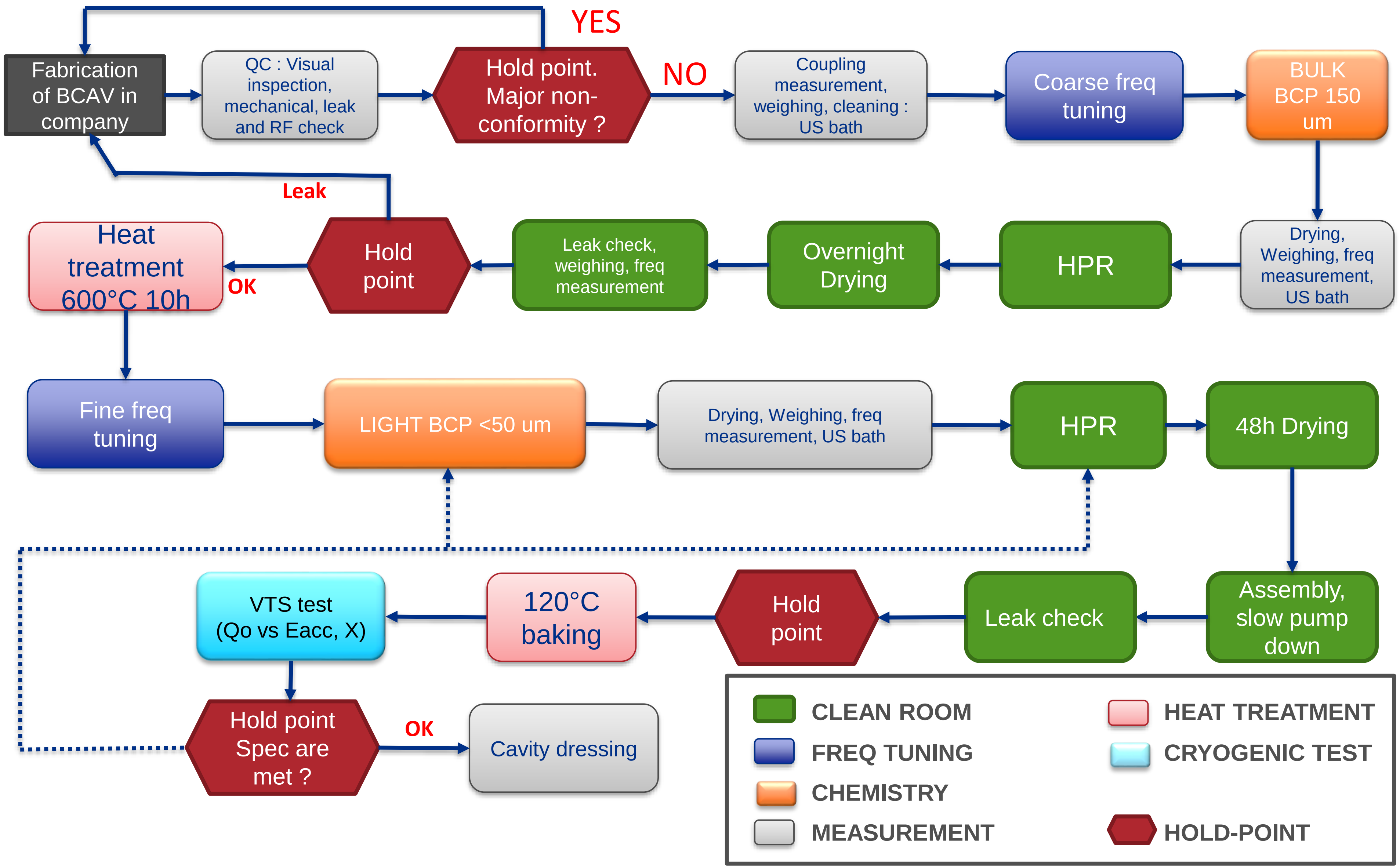
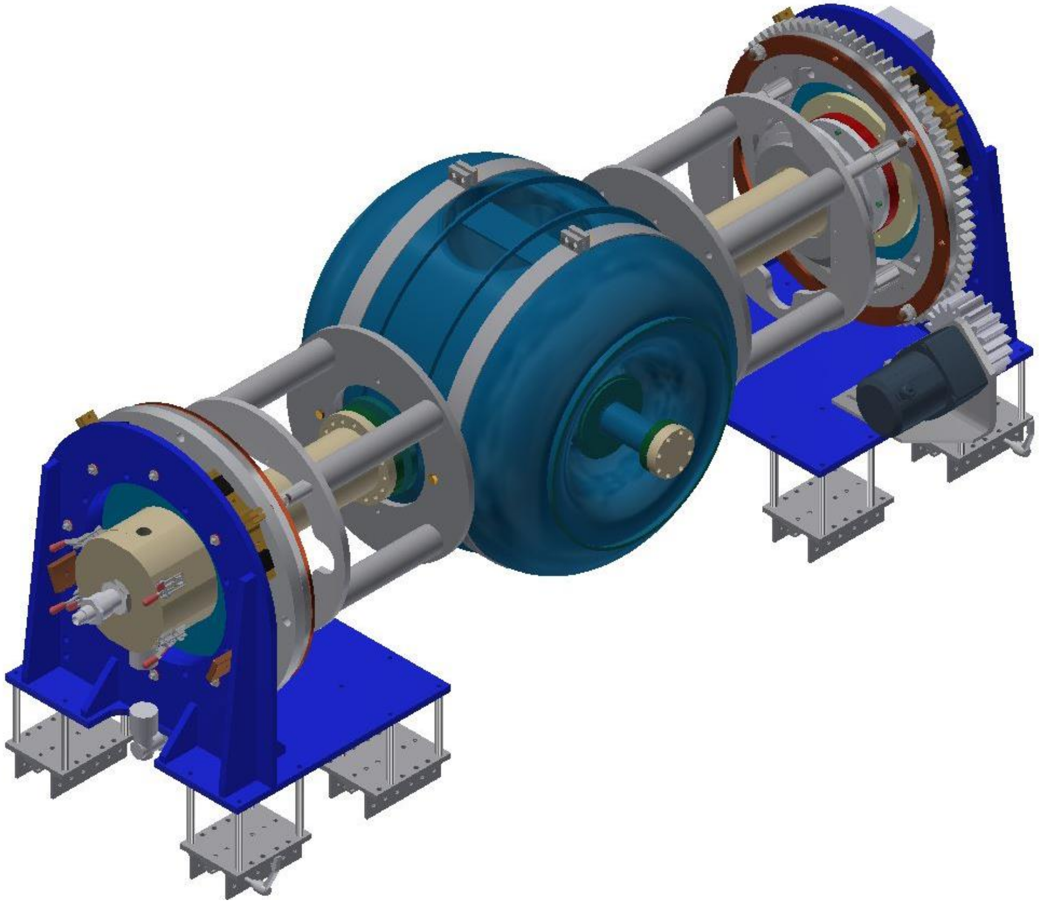
A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

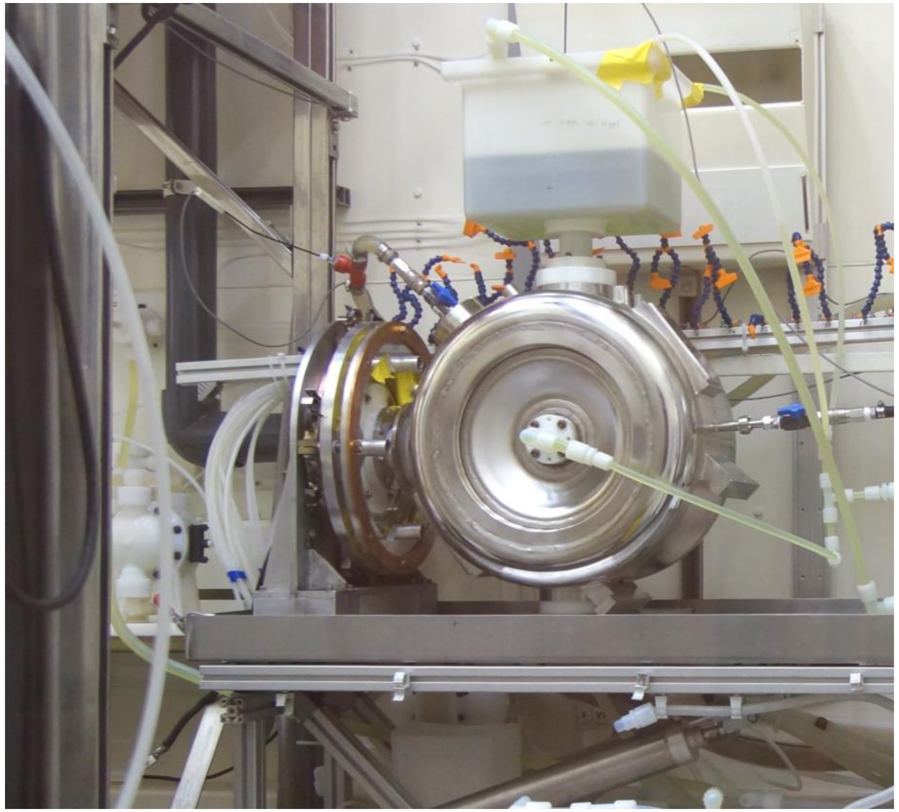
# SSR2 bare cavities processing and testing flow



# SSR2 bulk and light rotational BCP

- Both bare and Jacketed SSR2 BCP will be done at ANL facility, following RFD cavity experience: rotational BCP through both CP and VP.





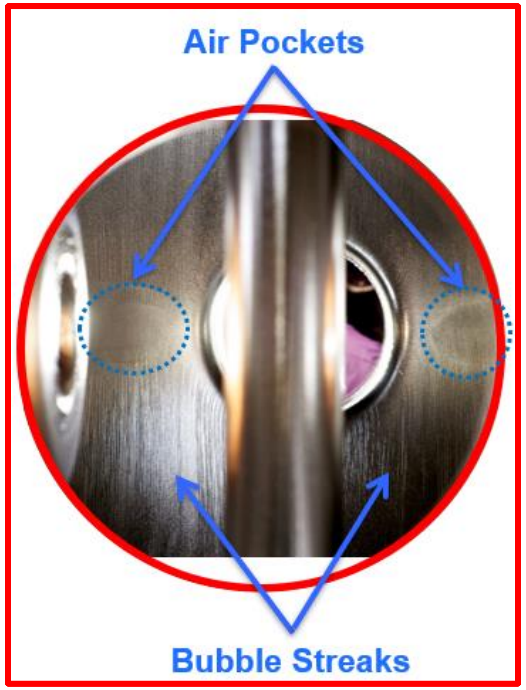
SSR2 cavity model on rotational BCP tool at ANL

SSR1 cavity during conventional BCP at ANL

# Reasons for rotational BCP, experience with RFD cavity I

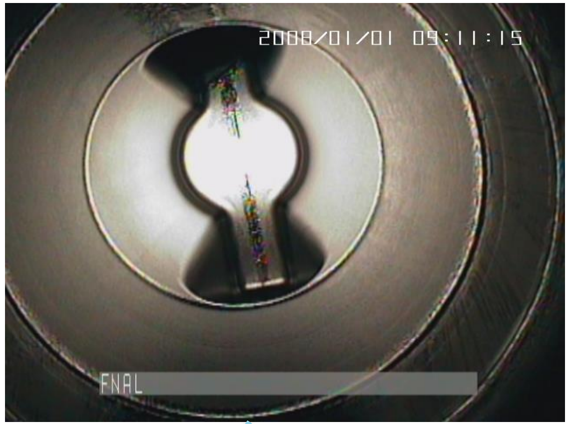
- Visual inspection after light rotational BCP showed the inner surface has a uniform matte looking.
- No signs of long and big bubble traces: slow rotation is preventing big bubbles formation in the acid mixture!
- **No signs of residue, air pockets or bubbles on the RF surface**

Rotational BCP tool for RFD cavity at ANL

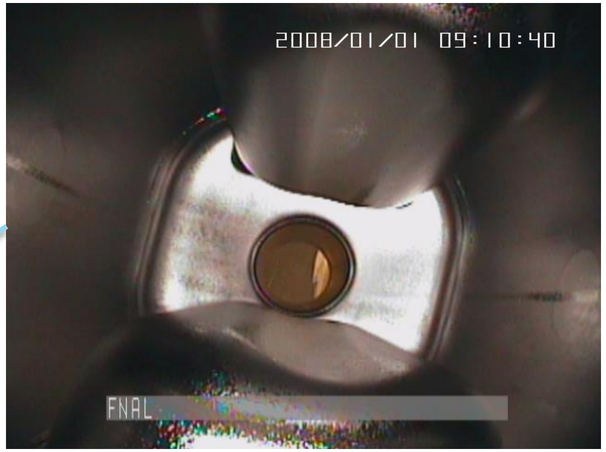



SSR1 RF surface after conventional BCP


Beamtube1view




HHOM view

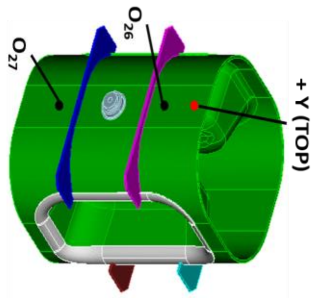


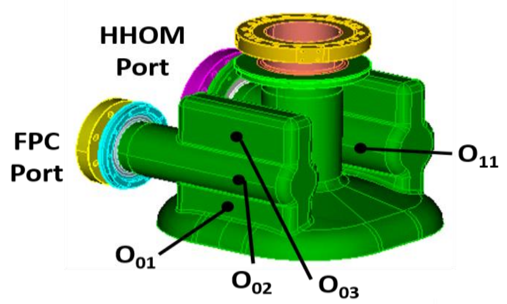

Beamtube2 view

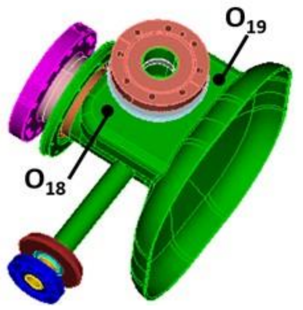
# Reasons for rotational BCP, experience with RFD cavity II

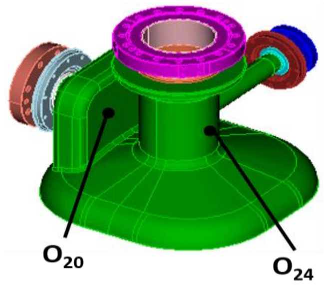
- Material removal has been compared between the two BCP procedure: AVG removal is 48 microns for ANL, 40 microns for conventional BCP.
- **Uniform removal confirms better process compared to BCP prfformed on static RFD: Standard deviation in etch data drops going from conventional to rotating cavity BCP.**

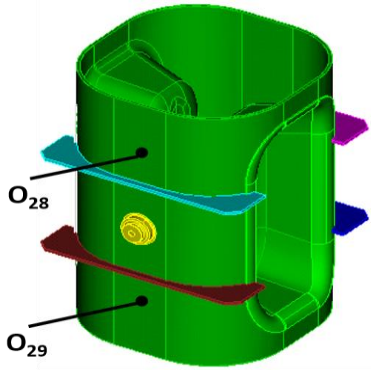
| Location | ANL BCP 48 µm | conventional BCP 40 µm |
|---|---:|---:|
| HHOM | 46.1 | 22.5 |
| VHOM | 55.0 | 58.6 |
| FPC | 48.6 | 28.4 |
| BODY | 44.5 | 25.1 |
| POLE (left) | 51.8 | 26.2 |
| POLE (right) | 51.3 | 28.7 |
| MAX | 66 | 213.7 |
| MIN | 25.4 | 8.5 |

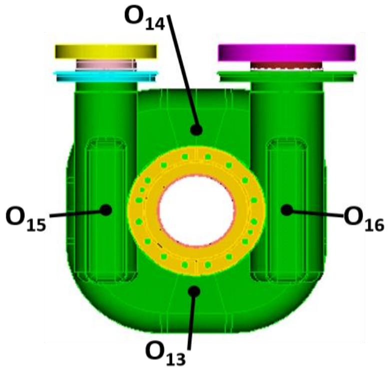


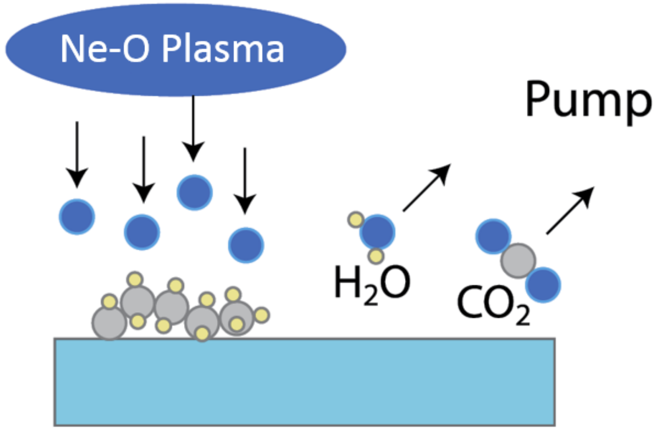



# Innovative techniques: Plasma Processing for MP reduction

- **Reducing FE by increasing work function** of cavity RF surface
  - Hydrocarbon contaminants observed on all Nb cavities
  - Hydrocarbons and adsorbates lower work function of Nb
- Enabling operation at higher accelerating gradients
- **Potential benefits for multipacting barrier mitigation**

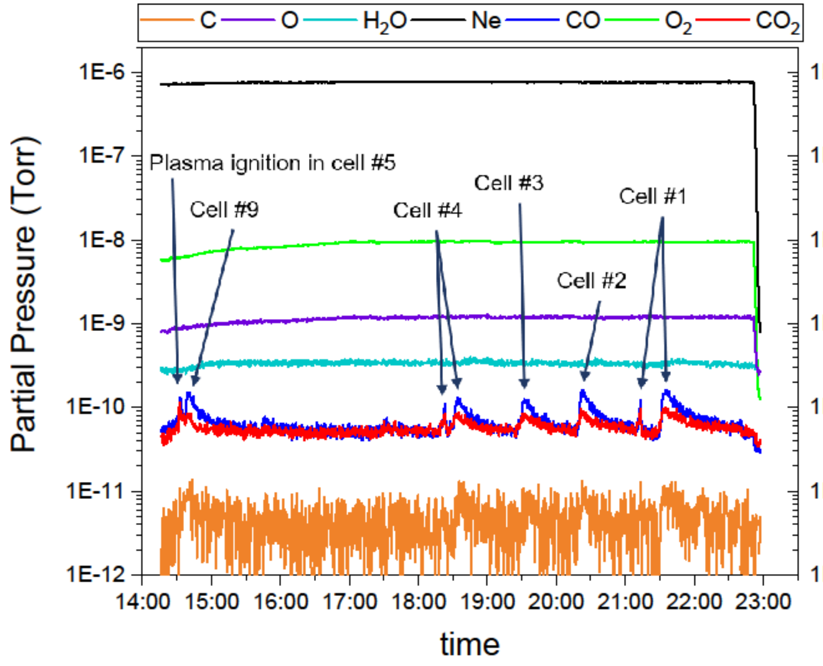



$$j = \beta \frac{AE^2}{\Phi} e^{-B\frac{\Phi^{3/2}}{\beta E}}$$

$J$: current density
E: surface electric field
$\Phi$: work function
$\beta$: enhancement factor (≈10 to 100)
A,B: constants

$$dj = 0 \qquad \frac{dE_{acc}}{E_{acc}} \approx \frac{3}{2}\frac{d\Phi}{\Phi}$$

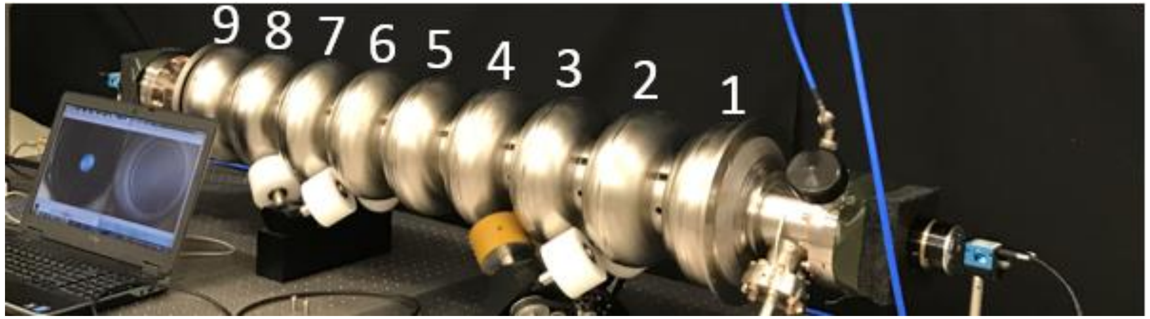
**Increasing $\Phi$ by 10 % means increasing $E_{acc}$ of about 15 %**

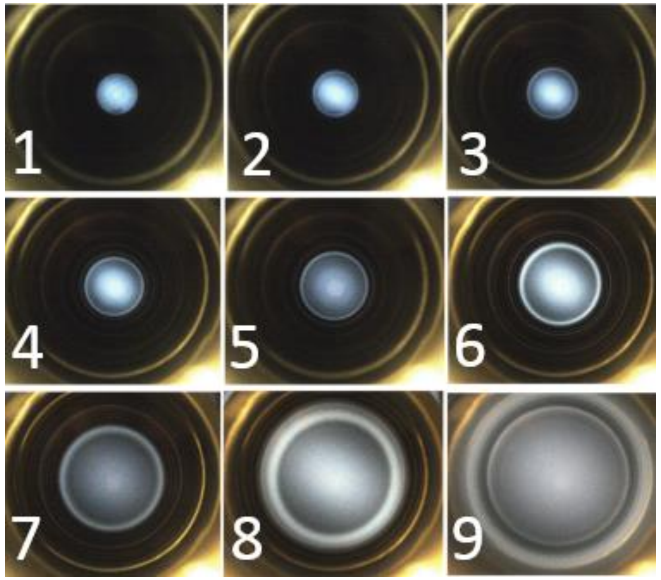


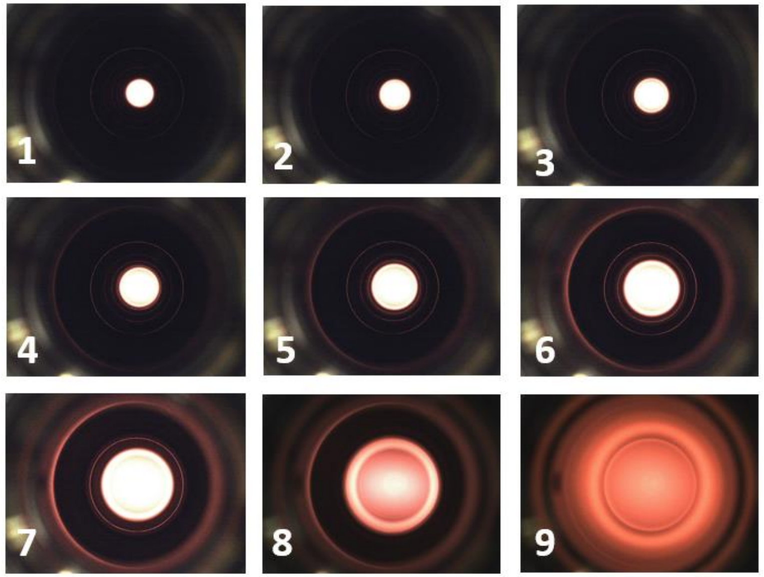

M. Doleans et al. NIMA 812 (2016) 50-59

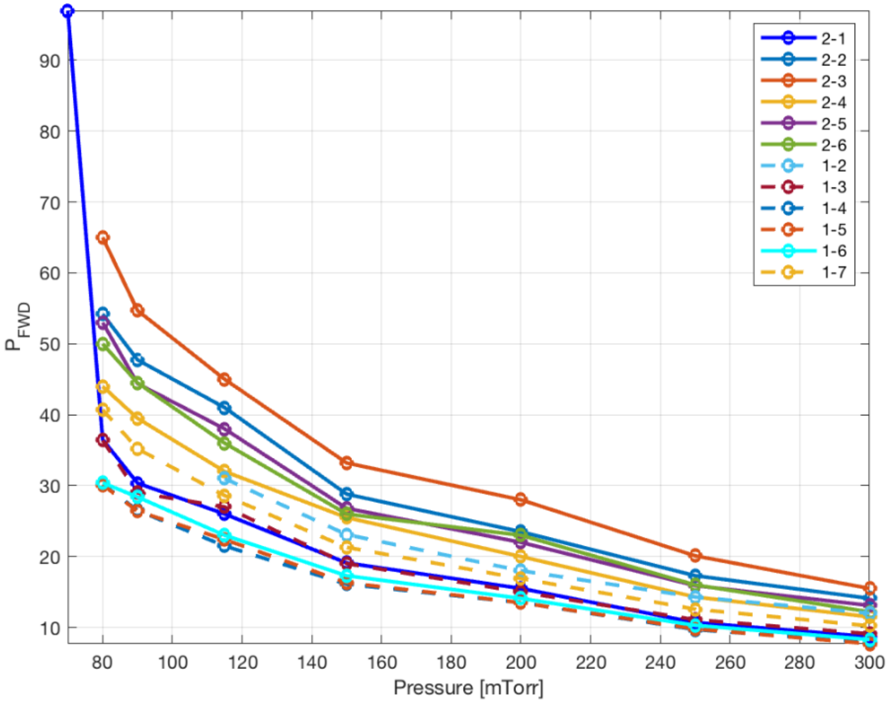
# Plasma ignition experience at FNAL: 1.3 GHz 9-cell cavities

- Plasma has been ignited in each cell of a 1.3 GHz cavity using HOMs
- **The technique has been validated for 1.3 GHz 9-cell cavities, ignition curves for both Ar and Ne at different pressures have been measured**



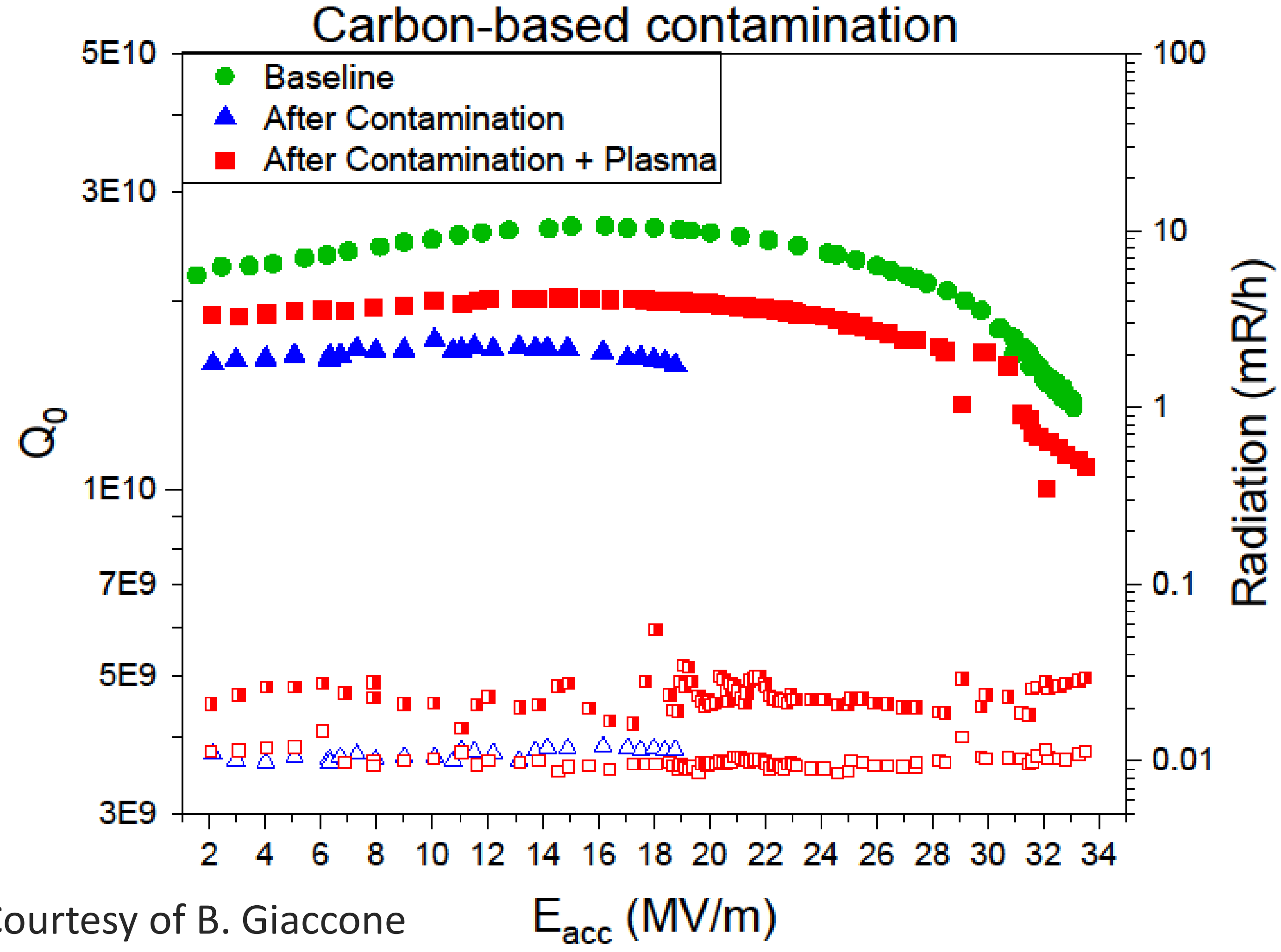




- Plasma ignition power has been measured for LCLS-II cavities using different HOMs, **$P_{FWD}$ as low as 10 W!**

# Plasma processing results at FNAL: cleaning carbon contaminants

Test on single cell cavity:

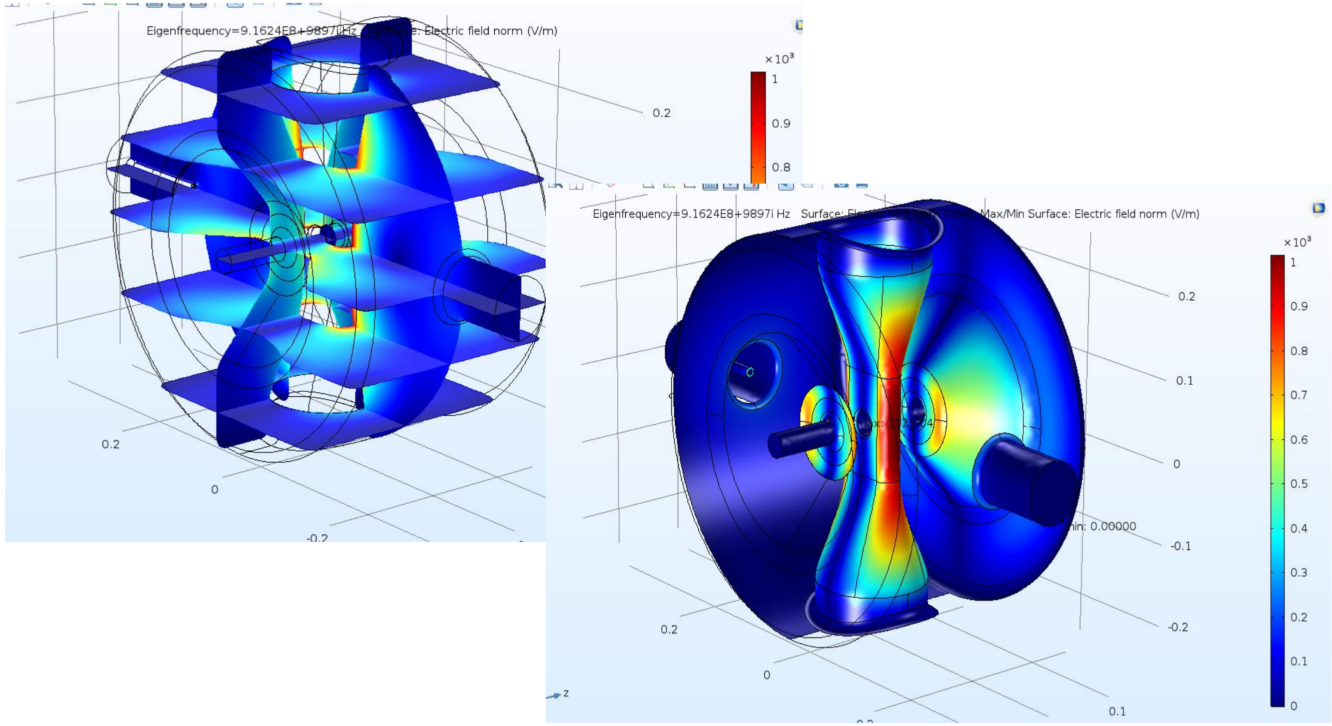
- contaminated with Aquadag (carbon based conductive paint) on Iris locations
- Plasma processing 1-cell for 17 hrs.



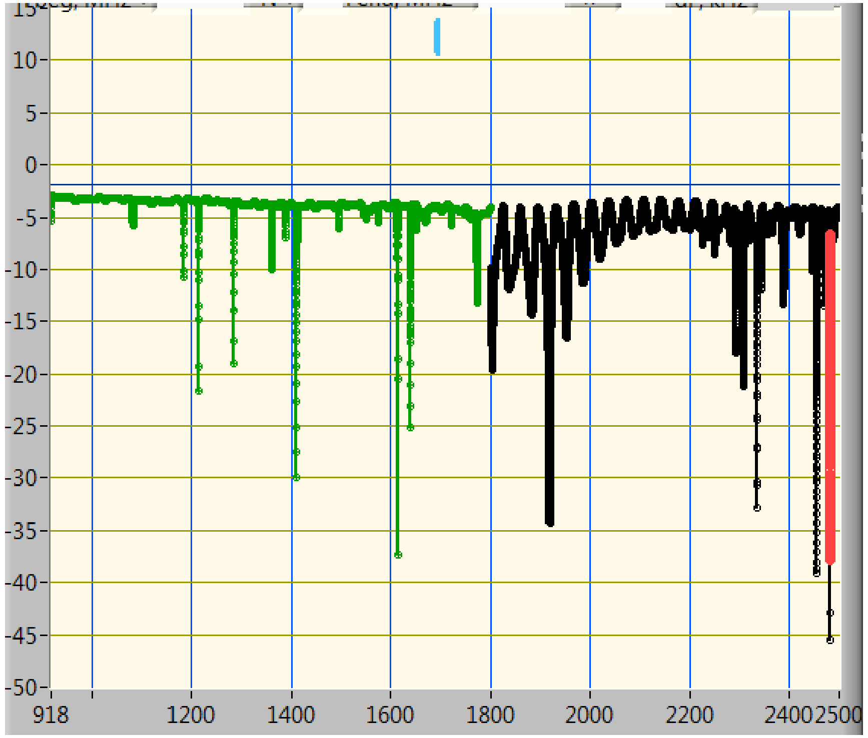

Courtesy of B. Giaccone

# HOMs plasma ignition in SSR1 spoke cavities

- Spoke resonators may benefit from plasma cleaning (MP processing, FE), usually $Q_0$ at RT is ≈5E3: lower than multi-cell structure → coupler-cavity mismatch very high at RT.
- HOMs can couple to FPC better than fundamental mode at RT!
- Drawback: HOMs in spoke cavities have complicated field distribution…see example below.



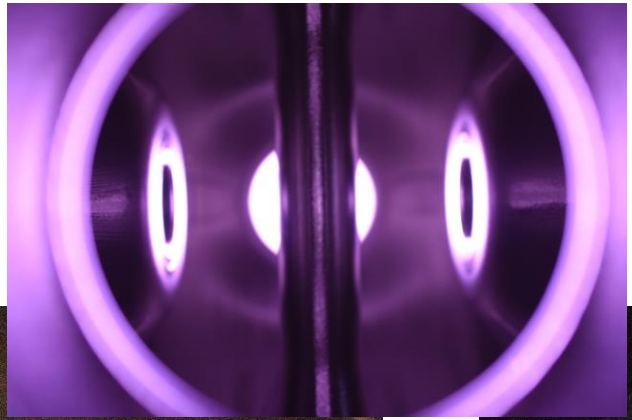

Example of Volume and Surface field distribution of HOM in SSR1 (FNAL)

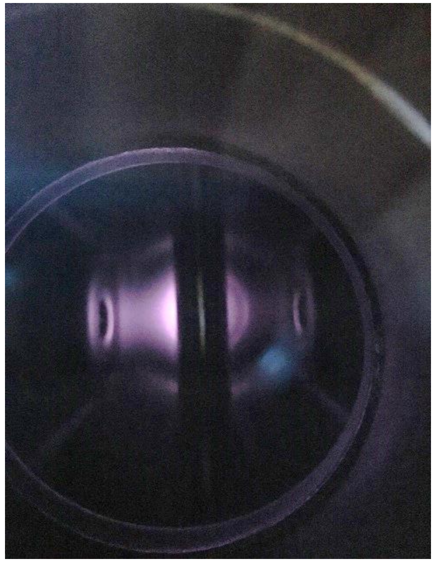


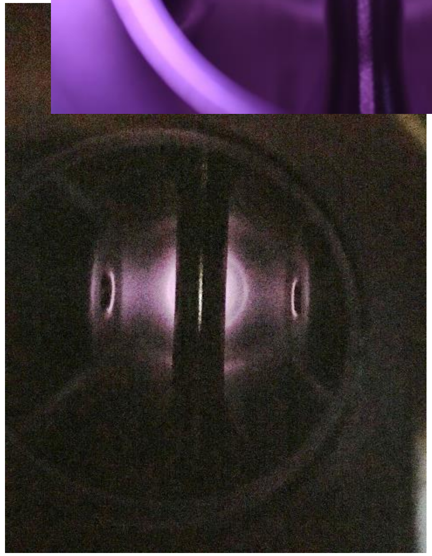

S11 measurements of SSR1 FPC

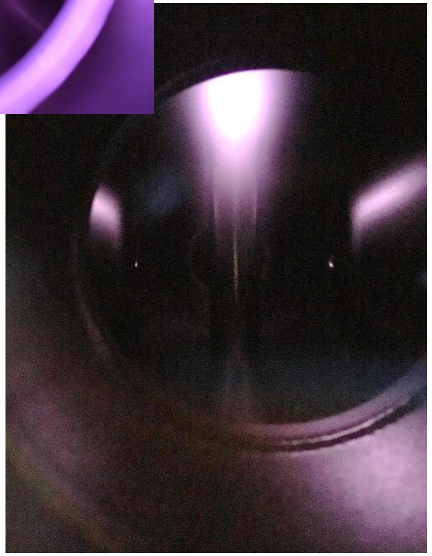
# Plasma ignition SSR1 spoke cavity

- Ar at 250 mTorr requires RF power ranging from ≈2W to ≈30W (depending on the mode) to ignite glow discharge.
- Plasma distribution follows electric field distribution.
- Correct mix of modes to ignite areas of interest:
  - accelerating gaps
  - spoke base
  - spoke side
  - cylindrical shell

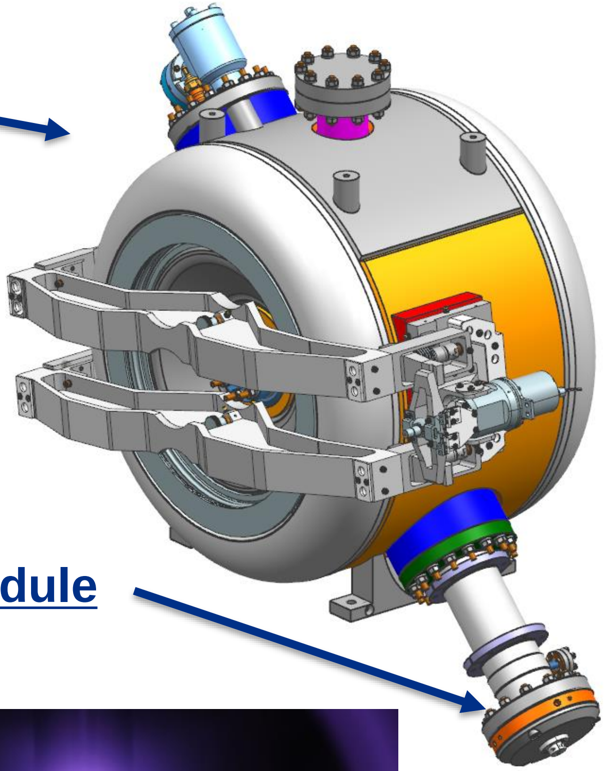




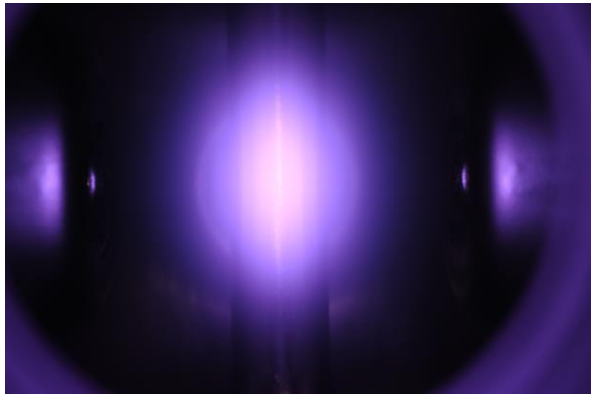




PU flange view-port for plasma visual detection



**SSR1 Cryomodule FPC**



# Conclusions

- Rotational BCP appears to be superior to conventional BCP:
  - Controllable etching rate, **material removal uniformity improves drastically**
  - Surface finish still matte, **no bubble streaks or air pockets with rotation**
- Fundamental to initiate technology transfer to cavity vendors to improve cavity surface preparation for PIP-II and future particle accelerators (low-beta and low frequency cavities)
- **FNAL is looking into developing rotational BCP at cavity vendor**
- Plasma processing has been successfully implemented at FNAL (LCLS-II), **plasma ignition successful on SSR1 cavity!**
- Plasma cleaning effects on the Nb SEY will be studied → huge benefit in conditioning cavities before test/operation